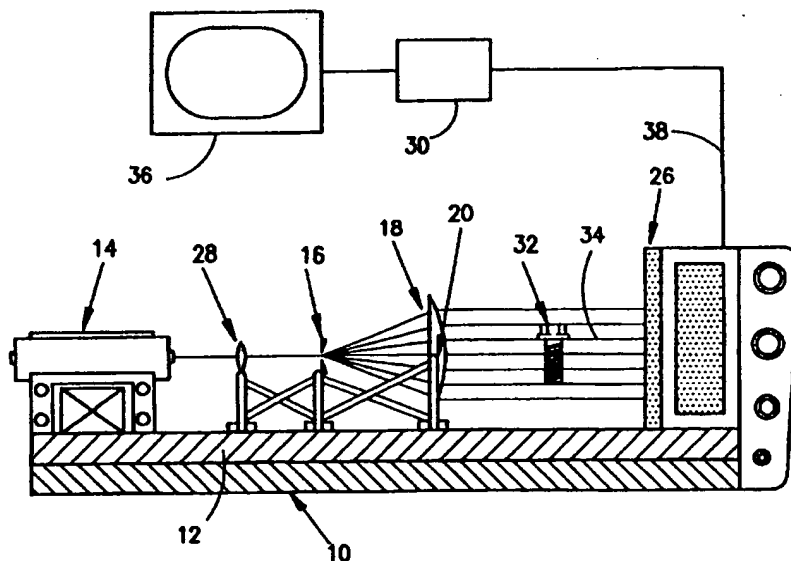


**PCT**WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : <b>G01B 11/02</b>	<b>A1</b>	(11) International Publication Number: <b>WO 97/21072</b> (43) International Publication Date: 12 June 1997 (12.06.97)
(21) International Application Number: PCT/US95/14950 (22) International Filing Date: 5 December 1995 (05.12.95) (71) Applicant: SHERIKON, INC. [US/US]; Suite 2500, 14585 Avion Parkway, Chantilly, VA 22021 (US). (72) Inventor: MUFTI, Asif; Suite 2500, 14585 Avion Parkway, Chantilly, VA 22021 (US).	(81) Designated States: AU, BR, CA, JP, KR, MX, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report.	

(54) Title: HIGH SPEED OPTO-ELECTRONIC GAGE AND METHOD FOR GAGING



## (57) Abstract

A non-contact gaging method and apparatus develops the sharply defined silhouette spanning opposite edges of an object (32), measuring the silhouette of bolts (32) and other threaded fasteners, to determine thread pitch, pitch diameter, major and minor diameter, flank angle, length of thread engagement and other fastener dimensions, to high accuracy. A laser (14) provides a beam which is focused by an object lens (28) on a pinhole in a shade (16), providing a point source from which the beam diverges. A collimating lens (18) produces a collimated broad illuminating beam (34) of laser light dimensioned to encompass the object (32). The illuminating beam is incident on a planar two-dimensional detector array (26). An image processor (30) counts pixels between light/dark transitions to provide precise dimensional measurements that are compared to stored values to reach an accept/reject decision as objects (32) pass the gaging system.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LJ	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

## 5 HIGH SPEED OPTO-ELECTRONIC GAGE AND METHOD FOR GAGING

Background of the Invention1. Field of the Invention

The invention relates the field of opto-electronic methods and apparatus for quickly and automatically  
10 gaging the dimensions of precision objects. In particular, the invention concerns video image collection and analysis for rapid gaging of the dimensions of workpieces such as fasteners comprising threaded screws or bolts, using collimated laser imaging  
15 techniques to obtain a precise two dimensional pixel image subject to data analysis, whereby precise measurements are taken from a pixel image silhouette of the respective workpiece.

2. Prior Art

20 Mechanical fasteners, threaded and unthreaded, are widely used in our technological society. In many applications, certain dimensions of the fasteners are critical to how well and smoothly the fasteners engage mating fasteners. There is a need for precise gaging to  
25 assess the quality of such fasteners with respect to dimensions. However, for practical considerations it would be advantageous if the accuracy, completeness and speed of gaging could be maximized, while at the same time minimizing the complexity and expense of the gaging  
30 method and apparatus.

There are a number of criteria by which the quality of fasteners can be assessed. Several characteristics of threaded fasteners such as screws, bolts, threaded shafts and the like, are very apt to provide a useful  
35 measure of their quality. These include, for example,

5 shank diameter, perpendicularity, eccentricity and  
certain specific thread measurements such as minor and  
major diameter, thread pitch, pitch diameter, flank  
angle, length of thread engagement and the like. By  
10 comparing the actual dimensions of fasteners to maximum  
and minimum tolerances in each of these respects, one  
can obtain a good measure of how well the fasteners will  
fit a mating fastener, a machined opening or the like.  
Parts can be accepted and rejected on this basis as a  
part of quality assurance steps. On the other hand, any  
15 measurements advantageously are accomplished at least as  
quickly as the parts are produced, so that quality  
assurance does not become a bottleneck. Generally, it  
has been necessary to make tradeoffs between quality  
assurance measurement and production speed, for example  
20 by taking fewer than all the measurements that would be  
advantageous from a quality assurance standpoint, or by  
sampling the parts and only taking complete measurements  
on a subset of the parts to assess the quality of all  
the parts.

25 Prior art devices and methods take at least one  
minute or more to accurately gage a fastener's  
dimensions. Because of this, it is not possible to  
timely gage each fastener in a batch of fasteners to  
determine if each falls within a specific tolerance. It  
30 is not uncommon that only a small percentage of the  
fasteners in a batch be gaged. Sometimes this  
percentage is as low as one one-hundredth. If this  
select group passes, the entire batch is accepted as  
passing.

35 Various methods have been disclosed for measuring  
fasteners as to those particular dimensions that are  
considered the most important. Such measurements can be  
more or less automatic. The vast majority of such  
methods involve the use of mechanical devices such as  
40 feeler gages comprising wires, balls and pins or

5 micrometers, which physically bear against the fastener  
to be dimensioned. The primary disadvantages of such  
methods are that they are time consuming, often required  
manual action by an operator, are subject to operator  
error due to fatigue, difficult to standardize or keep  
10 calibrated, and generally are not conducive to  
automated quality assurance inspection as a production  
step.

The invention is directed to a particular opto-  
electronic method and apparatus for taking high speed  
15 non-contact measurements in an automated manner.  
Optical detection of objects has been attempted in the  
prior art for making dimensional measurements, and  
generally involves either illuminating an object or  
backlighting it, and then detecting transitions of  
20 luminance characteristic of edges. For outer edges of  
an opaque object, accurate object edge detection is  
possible by employing back illumination of the object to  
produce a transition in light intensity in a collected  
image, between the dark object, more accurately its  
25 backlighted silhouette, and the bright background.  
Where the object is placed immediately in front of a  
diffuse backlight source, a focused image of the object  
can be collected.

A laser beam can be arranged in a collimating  
30 optical system for taking a measurement. For example,  
in U.S. Patent No. 3,941,484 - Dreyfus, an object is  
backlighted by use of a laser and a collimating lens or  
mirror that expands the point source laser light to  
encompass an object to be examined. The object partly  
35 occludes the expanded beam and provides an image.  
Additional lenses concentrate the beam at a point or  
scanning tube arrangement, such that the luminance of  
the collected light is serialized like a raster image.  
The serial luminance level is sampled repetitively in  
40 conjunction with a threshold comparator and timing means

5 to locate the edge of the object from a change in the  
amplitude of the luminance signal. The comparator data,  
in connection with timing data, can be converted into a  
dimensional measurement.

10 A scanning arrangement is inherently serial, and as  
a result, the scanner can sense light intensity from the  
beam at only one position at a given time. Timing  
considerations affect the accuracy of the measurement.  
Moreover, scanning arrangements are prone to further  
error if one attempts to apply them to moving part.

15 U.S. Patents 4,576,482 and 5,114,230, both to  
Pryor, disclose methods in which collimated laser light  
is used as a back-light to collect luminance information  
by finding the transition in luminance across a single  
edge of an object. The light is partly occluded by the  
20 object and is applied to a linear photodiode array  
having an extension perpendicular to the edge. The  
object can be a cam or the like that is rotated in  
conjunction with the measurement to define the contour  
of the cam surface. The Pryor technique is also serial  
25 in that it detects the luminance transition along a  
line. The collimated beam is not wide enough to profile  
both edges of the object simultaneously. Furthermore,  
an array is not used to detect the resulting silhouette.

U.S. Patent 4,315,688 - Pryor discloses utilizing  
30 reflected light rather than an occluded backlight  
source, to check the quality or at least presence of  
fastener threads. Reflected light typically produces  
low accuracy measurements when used to gage fastener  
dimensions. An image of a portion of the threads of a  
35 fastener is created on a single sensor and the output  
signal is analyzed to determine thread quality.

It is known to collect and analyze a two  
dimensional image of an object by opto-electronic  
methods employing digital video imaging means, including  
40 performing dimensional measurements. An image of an

5 object or its profile is focused on a two dimensional  
detector array, for example of a video camera. The  
image is digitized, often together with image  
enhancement techniques intended to produce better edge  
contrast. A computer or other electronic processing  
10 device processes the digital information to locate edges  
and other relevant image points by finding transitions  
in luminance. Various object dimensions are then  
determined from the pixel position displacements between  
transitions in luminance. With a proper setup,  
15 measurements can be made quickly and accurately, even of  
objects moving rapidly on an assembly-line conveyor.  
The accuracy of the measurements performed with such  
methods is limited by several factors, including the  
fidelity of the input image. A number of factors  
20 influence image quality, the specifics of illumination,  
imaging optics, the detector, and the placement of the  
object to be measured play dominant roles.

Thread quality gaging is a particularly demanding  
imaging problem that has not been solved completely by  
25 digital imaging methods, especially where use of a lens  
is involved. The invention eliminates a need for a  
focusing lens. Previously it was necessary to  
accurately position the focusing lens in space a certain  
distance from the object being measured in order to  
30 produce a shadow identical in size to the object. In  
the invention, use of collimated light is instrumental  
in providing a shadow which is the same size of the  
object, without a need for a lens and the attendant  
problems of correctly positioning the lens with respect  
35 to the object and otherwise focusing the image.

U.S. Patent No. 4,644,394 - Reeves discloses  
examining external threads on a pipe, using a collimated  
laser beam to back-light the threads along one side of  
the pipe. A luminance transition thus is detectable at  
40 a tangent of the pipe surface. An image of the pipe

5 threads at one angular point on one side of the pipe is collected and processed and enables certain thread measurements in that area. However, in order to make related thread measurements at other angular points around the pipe, for example to determine pipe diameter  
10 or to relate thread data in different areas, it is necessary to rotate the pipe or to move the camera around the pipe axis (keeping the collimated source aligned to the camera). A metered rotation drive means can be used to rotate the pipe (or orbit the camera and  
15 source), so as to enable the data applicable to different points along the threads to be related together. For example, one then can associate the data at 180 degree opposite points for measuring diameter. However, it is necessary to rely on the accuracy of the  
20 rotation drive means and the ability to accurately position the part at different angular positions around the rotation axis. These drive requirements introduce time constraints and measurement inaccuracies.

Three patents assigned to the Boeing Company (U.S. Patents 5,150,623, 4,828,159 and 4,823,396) disclose digital imaging methods which utilize back-lighting to gage fastener dimensions. U.S. Patent 4,823,396 - Thompson discloses a method in which a fastener is back-lit by an array of LED's (light emitting diodes). A  
30 video image is created of the fastener profile, which is then digitized and processed to verify thread presence, discriminate between fasteners with helical and parallel threads, measure thread length and perform various dimensional measurements on the head and shank of the  
35 fastener. The accuracy of the measurements performed is dependent on the distance between the camera lens and the fastener. Without collimated back-lighting, slight variations in the distance translate to variations in the apparent size of features in the image on the camera  
40 detector array, and consequently measurement errors.



5 Such uncertainties are significant when fasteners must be dimensioned to within tight tolerances, for example for use in the aerospace industry.

Patents 4,828,159 and 5,150,623 both issued to Woods, disclose methods which attempt to remedy the  
10 above problem by using two cameras, imaging the fastener from two orthogonal directions and mathematically calculating the position of the fastener at the time of imaging. The calculation of precise fastener position is dependent upon precise focussing of the cameras. An  
15 image that is even slightly out of focus will lead to an error in the calculated position, and consequent error in measured fastener dimensions.

#### SUMMARY OF THE INVENTION

An object of the invention is to provide a non-  
20 contact means for gaging the quality of a plurality of fasteners.

A further object is to provide a video image method and device for which variations in fastener positioning with respect to the detector array have minimal impact  
25 upon fastener dimension measurements.

Another object is to minimize labor-related errors by providing an apparatus and method which is simple to use and involves a minimum of component parts.

Yet another object is to provide a method and  
30 apparatus which does not suffer from the measurement uncertainties created by an out of focus image or image degraded by lens aberrations introduced through the use of an image lens.

Another object is to provide a method for measuring  
35 fastener dimensions that can be standardized and that will lend itself to the inspection of fasteners at the high rate of speed necessitated by high speed production methods.

A further object is to improve the accuracy and

5 speed of fastener measurements by collecting  
simultaneously pixel data representing a full silhouette  
of a part illuminated by a collimated back-lighting  
laser incident on a detector array, whereby dimensions  
can be determined directly from the pixel displacement  
10 of luminance transitions, i.e., to collect highly  
accurate data on both edges of a fastener at once.

These and other objects are satisfied according to  
the invention, while also solving the problem of  
fastener placement. The invention preferably employs a  
15 non-contact method and apparatus for gaging the  
important dimensions of a plurality of fasteners for  
production reporting, quality assurance,  
selection/rejection decisions and the like. Dimensions  
are determined rapidly and to high accuracy by using  
20 customized software developed inhouse. A fastener whose  
dimensions are to be determined preferably is positioned  
by mechanical means immediately opposite a two  
dimensional solid state detector array, of the kind used  
in CCD or CID cameras. The fastener can be positioned,  
25 for example, by means of a vacuum chuck or conveyor  
bracket, so that the fastener is disposed with its long  
axis in a known orientation, e.g., substantially-  
vertical. It also is possible to manually position the  
fastener. The fastener is back-illuminated by a highly  
30 collimated laser beam which impinges on the detector  
array at normal incidence, providing parallel light rays  
oriented perpendicular to the longitudinal axis of the  
fastener. The laser beam is opened by collimating means  
to encompass at least two opposite edges of the fastener  
35 simultaneously. The fastener occludes or eclipses part  
of the beam, thereby producing a silhouette of the  
fastener. Due to the collimation of the beam the  
silhouette can be cast on the detector array without the  
use of an interceding imaging lens for focusing.

40 The detected luminance of the image is digitized to

5 define pixel values encoded at least to discriminate  
light and dark pixels by comparison with a threshold  
luminance, and also potentially to permit image  
enhancement using gray scaling to precisely define  
edges. Image processing means are utilized to locate  
10 the silhouette edges and relevant points thereon to high  
(pixel or better) accuracy and fastener dimensions are  
then determined by appropriate proprietary algorithms.  
The decision to accept or reject a particular fastener  
is based upon comparison of such dimensions with  
15 customer or industry standards.

It is an aspect of the invention that by use of  
collimated laser back-lighting, for creation of a  
silhouette without the use of an imaging lens, and  
employment of a high precision CID detector array to  
20 parallel-load the silhouette image spanning at least two  
opposite sides of workpieces, a fast and efficient means  
and method for automatic workpiece inspection is  
provided. Inspection of each workpiece may be  
accomplished in as little as one second.

25 Use of a highly collimated beam for back-lighting  
according to the invention provides several advantages  
over prior art methods. The technique provides greater  
latitude in fastener placement. It minimizes the  
effects of minor changes in the distances between the  
30 fastener and the light source and detector array,  
thereby reducing the time for evaluation of the  
fastener. It also permits variation in the orientation  
of the fastener with respect to the detector array,  
which array is sized to encompass the silhouette such  
35 that accurate dimensions are quickly and readily  
obtainable from the pixel image data. It is possible to  
collimate the beam of laser light so that the angular  
divergence of parallel rays is as small as 1 arc-second.  
When an object is back-lit with such a beam, a 1cm  
40 variation of the displacement of the object from a

5 position 10cm from the detector array translates geometrically to only a 5 millionths of a centimeter change in the size of the silhouette produced on the array. This is about one-tenth the wavelength of the light and is inconsequential in comparison with errors  
10 introduced by diffraction effects and from other sources.

Image data on the part silhouette is collected in a strobe or snapshot fashion. This provides for the possibility of rotating a single fastener in place and  
15 taking images of various edge profiles, for example at regularly spaced angular positions around the longitudinal axis of the fastener. However, each of the profiles can provide full lateral measurements. Slight displacements of the light/dark transitions in the  
20 successive silhouettes, including displacements due to rotation, have minimal effect on the fastener silhouette or the measurements available by processing the image data. Finally, use of a highly collimated laser beam for back-lighting in conjunction with a two dimensional  
25 CID or CCD detector array ensures a precise, essentially one-to-one, correspondence between a fastener and its silhouette. Highly collimated laser beam illumination also minimizes grazing edge reflections which can make precise edge location difficult and hence degrade  
30 measurement accuracy.

Additional advantages are provided according to the preferred means for creating a silhouette of the fastener, wherein no imaging lens is provided between the fastener and the detector array for focusing the  
35 image. Measurement errors resulting from image degradation due to lens aberrations are eliminated. Since no focusing is required, fasteners of different diameters can be inspected with little or no adjustment to the setup. Since a full width silhouette of the  
40 fastener is incident on the detector array, with or

5 without the use of a condenser, diameter measurement errors that are inherent in metered rotation and/or successive illumination of opposite object edges with independent beams or with the same beam at different times, are avoided. By thus eliminating the need for  
10 precision fastener placement and the use of an orthogonal camera setup, the inspection procedure and mechanical requirements are considerably simplified. The invention thus makes possible a more compact and cheaper setup.

15 Since there is no imaging lens in front of the camera, diffraction effects are minimized by placing the fastener as close as possible to the camera array. For this reason the thickness of the transparent plate, placed in front of the two dimensional detector array,  
20 is kept to a minimum. The transparent plate is scratch resistant, resistant to breakage under mechanical impact and coated with an anti-reflective coating at the same wavelength as the interrogating laser beam. The procedure requires that once the collimated beam is  
25 incident on the two dimensional array the object, whose dimensions are to be determined, occludes the collimated beam. The diffraction effects are minimized by placing the object immediate to the transparent plate and hence to the two dimensional detector array.

30 The detector array can comprise light sensitive charge-coupled devices (CCD) or charge-injection devices (CID). Preferably, however, a CID array is used. Such a detector array has the advantage that its individual pixel detector elements are arranged contiguously, with  
35 no space between adjacent pixels. This makes possible the precise location of the object edges to within 15 microns in the pixel image. In addition, since each CID pixel is individually addressed, the x,y coordinates of each edge point can be accurately determined using  
40 direct data processing steps. Finally, CIDs provide

5 improved accuracy because they are immune to the  
"blooming" or streaking problems to which CCDs are  
subject when high intensity light source such as lasers  
are employed for fast imaging purposes. Although CCD  
arrays have recently been introduced which have  
10 contiguously arranged pixels and are resistant to  
"blooming", such CCD arrays are expensive as compared to  
CIDs.

CID and CCD detector arrays are known to increase  
in cost as array area is increased. Often the cost of  
15 a single detector array exceeds the cost of two detector  
arrays which are half its size. It is preferable,  
therefore, to use a detector array having a relatively  
small area. Occasionally, a fastener will have a  
dimension exceeding one or both of the height and width  
20 of the detector array. In such cases it is possible to  
employ two small detector arrays in a side-by-side  
arrangement to gage the over-sized fastener. In cases  
where the fastener has, for example, a width greater  
than the combined width of side-by-side arranged arrays,  
25 the arrays may be separated from each other as necessary  
to ensure that the far edge of each array is set-out  
from a respective edge of the fastener. The pixels of  
the arrays are appropriately re-addressed through the  
software. The system can be calibrated by placing a  
30 high precision ruler in the path of the collimated beam  
to cast a shadow on both detector arrays simultaneously.  
The data obtained is compared to the actual dimensions  
and adjustments made as necessary to the array  
positioning or addressing.

35 These and other objects and advantages of the  
invention will become apparent in connection with the  
following description of certain preferred embodiments  
of the invention and the accompanying diagrams.

5                    Brief Description of the Drawings

          There are shown in the drawings examples of  
embodiments of the invention as presently preferred. It  
should be understood that the invention is not limited  
to the precise arrangements and instrumentalities shown  
10 in the drawings, wherein:

          FIGURE 1 is a top plan view of the device of the  
invention.

          FIGURE 2 is a partly schematic side elevation view  
thereof.

15           FIGURE 3 is an end elevation view in the direction  
of illumination, i.e., from the left in FIGURES 1 and 2.

          FIGURE 4 is a front plan view of a silhouette image  
on a detector array as produced by the device of the  
invention.

20           FIGURE 5 is an elevation view of a fastener as  
imaged according to FIGURE 4.

          FIGURE 6 is a front plan view of a silhouette image  
of a rivet on a detector array as produced by the device  
of the invention.

25           It should be noted that the object or workpiece to  
be gauged is located in a collimated beam. Thus, since  
there is nothing between the object and the sensor  
array, a silhouette is cast on the array that is the  
same size as the object. There is a one-to-one  
30 dimensional relationship. This is called a collimated  
silhouette.

          For purposes of clarity, the object to be gauged is  
shown diagrammatically spaced from the sensor array.  
Actually, the objects can be located closely adjacent  
35 the optical array. In any event, because the beam is  
collimated, variations in the distance between the  
object and the optical sensor array will not materially  
effect the one-to-one relationship. It will be a  
collimated silhouette.

40

5        Detailed Description of the Preferred Embodiments

FIGURES 1 through 3 show a preferred embodiment of a fastener inspection device according to the invention. The system includes a steel plate 12, which can be disposed on a base vibration isolation system 10 for preventing vibrations from the conveyor or other workpiece transporting device from being communicated to the measurement system. A laser light source 14 is mounted on plate 12 at one end such that the beam axis is aligned with the longitudinal center-line of the plate 12. Also mounted on plate 12 and positioned along its center-line are certain optical components intended to remove random fluctuations from the intensity profile, to expand and to collimate the laser beam. The laser beam has a predetermined beam width as emitted from laser source 14 which is larger than the video camera array size. In order of increasing distance from the laser, an objective lens 28 focuses the laser beam at a point through the aperture of a pinhole in shade 16. A lens mount 20 and a plano-convex lens 18 are preferably used to collimate the laser beam. Collimating plano-convex lens 18 is normal to the optical axis, and is precisely spaced along the optical axis from pinhole shade 16 by a distance equal to the focal length of lens 18. Accordingly, the rays from the laser are aligned by lens 18 to be parallel to one another and to the optical axis, over a height and width that is larger than the height and width of the workpiece or part of the workpieces 32 to be imaged and measured.

35        A planar solid state video sensor array 26 is disposed behind the workpiece 32 and due to the parallel alignment of the beam rays receives a sharp silhouette of the workpiece regardless of precisely where the workpiece is located along the optical axis. No lens is provided in front of sensor array or camera 26. The

40



5 aperture of the pinhole 16, collimating lens 18, and camera 26 are oriented such that the axis and center of each lie along a line defined by the light propagation axis of the laser beam. The camera or detector array 26 likewise is oriented normal to this axis.

10 A fastener positioning system 22 positions the workpiece 32, in this case a threaded bolt, in the path of the collimated beam 34, between lens 18 and CID camera 26. An image processor 30 and preferably a display monitor 36 are coupled to camera 26, for example  
15 by cable 38, such that the luminance information for each pixel in detector array 26 is provided to the image processor.

The image processor 30 can include means for addressing the pixel elements in the detector array 26,  
20 an analog to digital converter (not shown), and associated timing means. The image processor can be triggered to commence an image measurement cycle whenever a workpiece 32 arrives in the field of view, and to collect a series of images as workpiece 32  
25 passes, preferably while being rotated by positioning system 22. The images are collected in a strobe or snapshot freeze-frame fashion.

The laser 14 outputs a narrow beam of light which impinges upon the objective lens 28 and is focussed  
30 through the pinhole aperture of shade 16 essentially at normal incidence. The objective lens 28 and pinhole 16 act to provide a point light source for the plano-convex lens 18. The beam emerging from pinhole 16 diverges radially from the pinhole located at the focal point of  
35 plano-convex lens 18. A portion of the light is intercepted by plano-convex lens 18, which refracts the light rays by an amount that is a function of their angles of incidence on the air/glass boundaries at the surfaces of lens 18. The laser beam is thereby  
40 collimated.

5           The distance between the pinhole 16 and the plano-concave lens 18, and the area of lens 18, are functions of the area of detector array 26, and preferably are chosen such that the collimated beam has a width substantially corresponding to the receiving area of  
10   array or camera 26. The rays of the collimated beam which emerges from the lens 18 are parallel to the optical axis of the lens and normal to the plane of the detector array 26. Between the plano-convex lens 18 and the camera 26, a collimated beam 34 with divergence of  
15   1 arc second or better can be produced.

          The fastener 32 preferably is suspended from the positioning system 22, for example via a vacuum chuck, with its axis within a few degrees of vertical. The fastener 32 is positioned so that it lies entirely  
20   within the collimated beam, and therefore casts its full shadow or silhouette on the detector array 26. Fastener 32 occludes part of the highly collimated laser beam 34, thus producing a dimensionally precise silhouette of the fastener on the detector array 26. FIGURE 4 is a  
25   diagram showing the silhouette image 44, superimposed on a pixel matrix 42 of the camera or detector array 26. As shown in FIGURE 4, the silhouette has dimensions corresponding to the size of the real object, namely a fastener 32 such as bolt 50, shown in FIGURE 5. The  
30   dimensionally precise silhouette 44 of the fastener 32 is subdivided by the illuminated or occluded individual pixels 42 of the detector array. Though not to scale, FIGURE 4 shows small dot size which represents the center of the pixels.

35           Figure 6 is a diagram showing the silhouette image 54 of a rivet superimposed on a pixel matrix 42 of the camera or detector array 26. As shown in Figure 6, the silhouette has dimensions corresponding to the size of the real object. The dimensionally precise silhouette  
40   54 of the rivet is subdivided by the illuminated or

5 occluded individual pixels 42 of the detector array.  
Though not to scale, Figure 6 shows small dot size which  
represents the center of the pixels.

The edge of the silhouette is determined by  
sampling the pixels in the dark region where the shadow  
10 is cast to obtain an average of gray scale values. The  
unshadowed pixels are subsequently or possibly  
concurrently sampled to obtain an average of their gray  
scale values. The average gray scale value of the  
shaded region is subtracted from the average gray scale  
15 value of the unshaded region and the result multiplied  
by 0.25 (25%). The processor searches for all pixels  
having the calculated number of these represent the edge  
of the fastener. It is important to avoid saturating  
the pixels with laser illumination. With this  
20 technique, an edge can be determined to better than  
1000th of an inch, and even greater to 100,000th of an  
inch if subpixel interpolation is employed and by  
employing a two dimensional array with smaller  
individual pixel dimensions.

25 The pixels are each classified as light or dark  
based on the luminance level detected at the respective  
pixel. This can be accomplished by analog or digital  
threshold comparison techniques. Image processing  
routines or by using the theory of diffraction for edge  
30 detection and incorporating it into the subroutines, as  
known in the art, can be applied to the pixel data to  
enhance the contrast of the edge and/or to better define  
the nominal edge, to eliminate isolated contrasting  
pixels and otherwise to enhance the image data.

35 The processor 30 also measures the silhouette image  
for critical dimensional features. For example, the  
major and the minor diameter of the fastener is  
calculated by counting the number of occluded pixels  
along horizontal lines through the image, at any or all  
40 of the thread positions. The count of occluded pixels

5 is multiplied by the known pitch or distance between the  
centers of the pixels, which of course are regularly  
spaced. All such calculations are accomplished in the  
programming of the processor, preferably measuring not  
only major and minor diameter, but also thread pitch,  
10 pitch diameter, flank angle, longitudinal length of  
thread engagement and other criteria. The measurements  
can be compared to stored selection criteria such as  
nominal measurements and tolerances for acceptable  
parts. A deflection apparatus (not shown) can be  
15 arranged downstream of the measurement system, and  
coupled to the processor to divert selected or rejected  
parts, or to sort parts based on the selection criteria  
and measurements.

The processor controls array or camera 26 for  
20 collecting one or more images of the fastener when in  
the field of view. The camera 26 preferably is  
electronically shuttered so that it records the  
silhouette when the fastener is located in the beam and  
occluding the detector array. An additional  
25 photodetector (not shown) can be provided to produce a  
triggering signal when the fastener is at a predetermine  
position and breaks a beam. According to a preferred  
embodiment, a CIDTEC<sup>TM</sup> camera operating in synchronous  
capture mode is employed. This CID camera makes  
30 possible precise image capture of moving objects without  
the use of a strobe light.

Image processor 30 can rapidly locate silhouette  
edges in the pixel image data, and the pixel pitch or  
center spacing allows measurements to be taken to an  
35 accuracy of better than one thousandth of an inch,  
thereby allowing accurate selection based on criteria  
such as thread profile and other fastener dimensions.  
Many of the pixel capture and data analysis functions  
can be performed with frame grabber/image processing  
40 boards, available for example from Data Translation<sup>TM</sup>.

5 Operations on the data output by those boards, such as  
measurement and analysis of the dimensions as compared  
to nominal dimensions, and control and timing functions,  
are performed with a standard computer workstation or  
laptop computer with sufficient processing speed, such  
10 as a computer having an Intel 486 processor or the like.

The fastener inspection system as shown and  
described can dependably determine pertinent dimensions  
of fasteners such as bolts, screws and the like, compare  
the measurements to selection criteria, and operate  
15 selection/rejection actuators, all at production speeds.  
These dimensions used to select or reject can include  
pitch diameter, flank diameter, major diameter, minor  
diameter, thread height, thread pitch, shank diameter,  
length of thread engagement, fastener perpendicularity  
20 and the like. It will be appreciated that other  
dimensions may also be pertinent with respect to  
fasteners or parts of a different character.

The invention has been described with respect to  
certain preferred embodiments but is subject to  
25 variation within the scope of the appended claims.  
Reference should be made to the following claims rather  
than the foregoing specification as indicating the true  
scope of the invention in which exclusive rights are  
claimed.

## 5 I Claim:

1. A video imaging device for determining the dimensions of an object, comprising:

a laser light source providing a propagating beam of laser light along a beam path;

10 means for diverging the beam, providing an angularly divergent beam from a point along the beam path;

means for collimating said angularly divergent beam, intercepting the angularly divergent beam and  
15 providing a two dimensionally expanded collimated beam of substantially parallel rays;

positioning means operable to position a workpiece to be imaged in the collimated beam, the collimated beam being sufficiently large to encompass at least two  
20 opposite sides of the workpiece, the workpiece partially occluding the collimated beam to provide a silhouette including edges corresponding to the two opposite sides;

an optical sensor array for detecting a pixel image of the silhouette, the sensor array comprising a  
25 plurality of discrete light sensitive elements, the collimated beam and the silhouette being incident on the sensor array;

a processor coupled to the sensor array operable to determine dimensions of the workpiece from the pixel  
30 image.

2. The device of Claim 1, wherein the means for diverging the beam produces a point light source at said point along the beam path, the beam diverging from the point light source.

35 3. The device of Claim 2, further comprising an object lens operable to concentrate the laser beam at

5 the point light source.

4. The device of Claim 1, wherein the means for diverging comprises a shade having an aperture, the laser beam being incident on the aperture in the shade.

10 5. The device of Claim 3, wherein the object lens concentrates the light on an aperture in a shade for diverging the beam from a point source defined by the aperture.

15 6. The device of Claim 1, wherein the means for collimating the beam comprises a plano-convex lens having a focal length, the plano-convex lens being disposed at a distance from the point along the beam path equal to the focal length.

20 7. The device of Claim 1, wherein the means for detecting the collimated beam comprises a charge injection device (CID) detector array.

8. The device of Claim 1, wherein the means for detecting the collimated beam comprises a charge coupled device (CCD) detector array.

25 9. The device of Claim 1, wherein the means for computing dimensions comprises a microcomputer.

30 10. The device of Claim 1, wherein the positioning means comprises a conveyor operable to sequentially convey successive workpieces into a position within said collimated beam and immediately adjacent the detector array.

11. The device of Claim 10, wherein said workpieces are threaded fasteners.

5           12. A video imaging device for determining dimensions of an object, comprising:

          a laser operable to produce a laser beam along an axis;

          a shade disposed along the axis, having a pinhole  
10   aperture to pass and diverge the laser beam;

          an objective lens disposed between said laser and said shade, for focusing said laser beam on the pinhole aperture, whereby the pinhole aperture forms a point light source;

15           a collimating lens along the axis, having a focal length and being spaced from the shade by a distance equal to the focal length, the lens collimating the laser beam and producing a collimated illuminating beam of parallel rays, the illuminating beam having a height  
20   and a width;

          a detector array comprising a plurality of discrete light sensitive sensors, the illuminating beam being incident on the detector array for illuminating pixel positions defined by the sensors, the detector  
25   array being planar and normal to the illuminating beam;

          means for disposing an object to be measured within the illuminating beam, whereby the object casts a silhouette on said detector array;

          an image processor coupled to said detector array,  
30   including a processor operable to compute dimensions of the object based on positions of edges of the silhouette defined by transitions in luminance between adjacent pixels positions as detected by the detector array.

13. The device of Claim 12, wherein the detector  
35   array comprises a charge injection device camera and wherein the detector array is exposed directly to the collimated illuminating beam, whereby the silhouette is casted on the detector array without an intervening focusing lens.



5           14. The device of Claim 12, wherein the detector array comprises a CCD camera and wherein the detector array is exposed directly to the collimated illuminating beam, whereby the silhouette is casted on the detector array without an intervening focusing lens.

10

          15. The device of Claim 12, wherein said detector array is comprised of rows and columns of pixels having a predetermined regular pitch spacing, and wherein the image processor is operable to count pixels between the  
15 transitions and to multiply a pixel count by the pitch spacing for obtaining a dimensional measurement of the object.

          16. The device of Claim 12, wherein the means for disposing the object in the illuminating beam comprises  
20 a conveyor operable to carry successive objects into the illuminating beam and immediately adjacent the detector array.

          17. The device of Claim 12, wherein said objects are threaded fasteners.

25           18. The device of Claim 17, wherein the image processor is operable to measure at least one of pitch diameter, flank angle, major diameter, minor diameter, thread height, thread pitch, shank diameter, length of thread engagement and fastener perpendicularity of the  
30 objects.

          19. A method for determining the dimensions of an object, comprising:

          using a laser light source having a propagating beam of laser light to product a laser light beam along  
35 a beam path;

          angularly diverging said beam from a point along

- 5     said beam path;  
          collimating said angularly divergent beam to  
          provide a two dimensionally expanded collimated beam of  
          substantially parallel rays of said beam;  
          positioning a workpiece to be imaged within the  
10    collimated beam, said workpiece partially occluding the  
          collimated beam thereby providing a silhouette of the  
          workpiece;  
          detecting a pixel image of said silhouette on an  
          optical sensor array; and  
15    computing dimensions of the workpiece from said  
          pixel image.

20. The method of Claim 19, further comprising  
concentrating the beam prior to angularly diverging the  
beam.

- 20       21. The method of Claim 20, wherein an objective  
lens is used to concentrate the beam.

22. The method of Claim 19, wherein a shade having  
an aperture is used to angularly diverge the beam, the  
beam being incident on the aperture in the shade.

- 25       23. The method of Claim 19, wherein a plano-convex  
lens having a focal length is used to collimate the  
beam, the plano-convex lens being disposed at a distance  
from the point along the beam path equal to the focal  
length.

- 30       24. The method of Claim 19, wherein a charge  
injection device (CID) is used to detect the pixel  
image.

25. The method of Claim 19, wherein a charge  
coupled device (CCD) is used to detect the pixel image.

25

5           26. The method of Claim 19, wherein a microcomputer is used to compute the dimensions.

          27. The method of Claim 19, wherein a conveyor is used to position the workpiece.

10           28. The method of Claim 24, wherein the CCD device has a plurality of discrete, light sensitive sensors defining said pixels.

          29. The method of Claim 25, wherein the CID device has a plurality of discrete, light sensitive sensors, defining said pixels.

15           30. The method of Claim 28, wherein the beam is incident on the CCD device for illuminating said discrete sensors.

          31. The method of Claim 29, wherein the beam is incident on the CID device for illuminating said  
20 discrete sensors.

          32. The method of Claim 29, wherein said silhouette is a collimated silhouette that is cast in a one-to-one dimensional relationship on said optical sensor array.

1/3

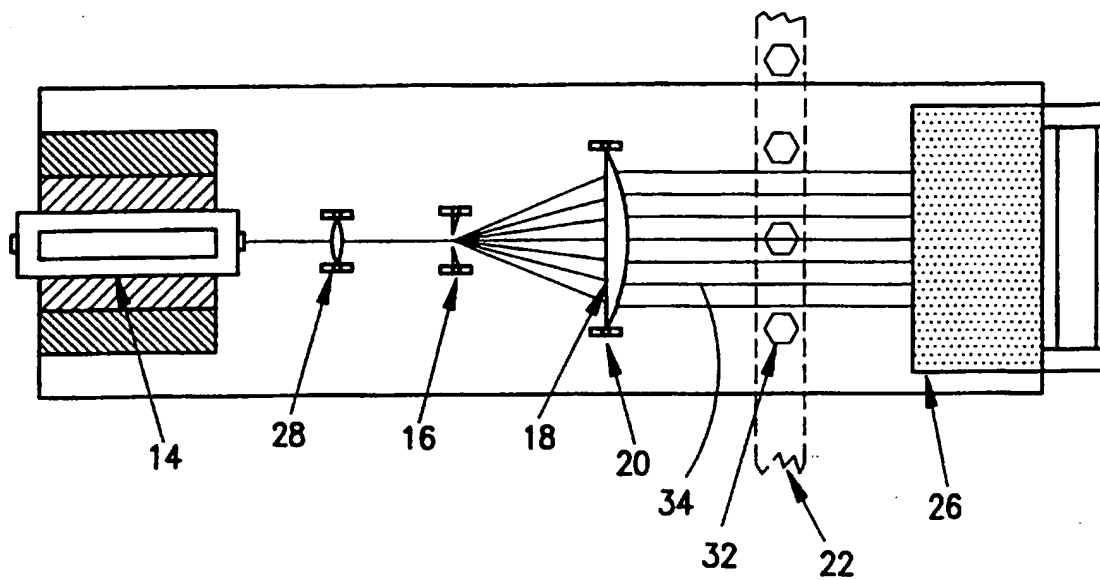


FIG. 1

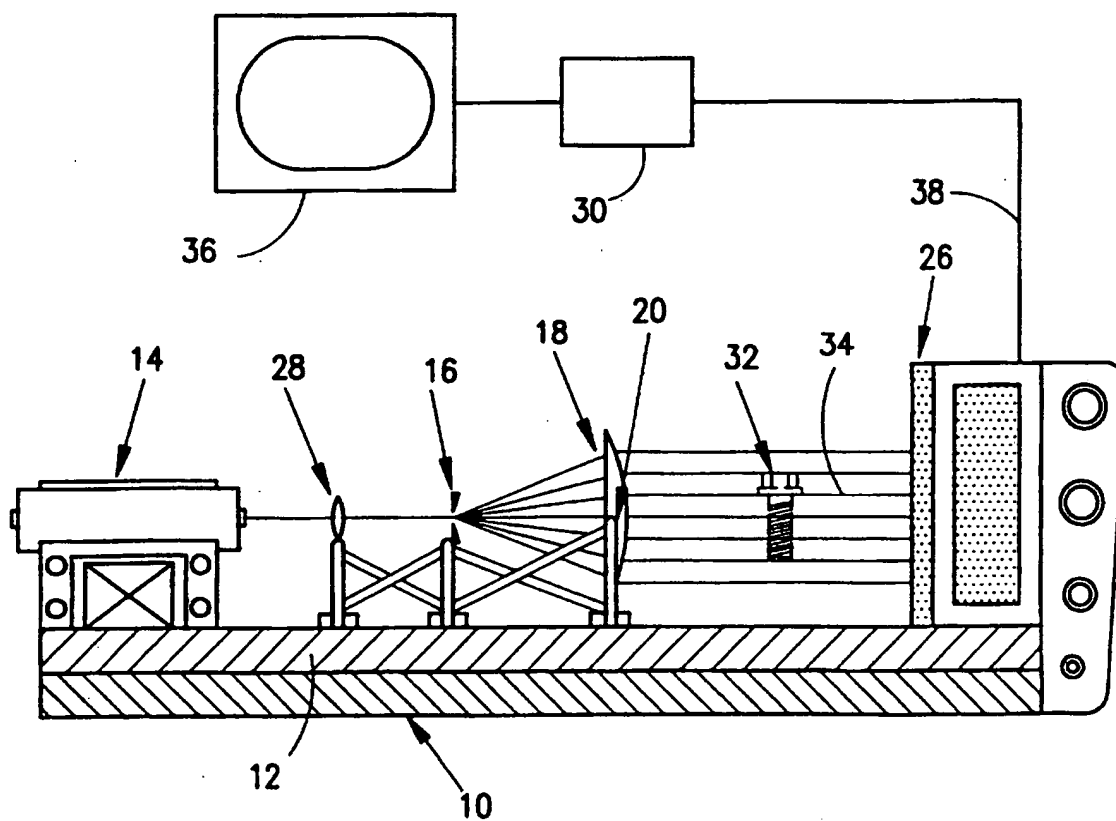


FIG. 2

SUBSTITUTE SHEET (RULE 26)

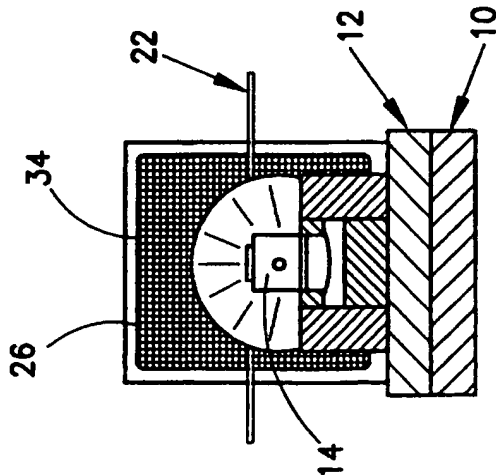


FIG. 3

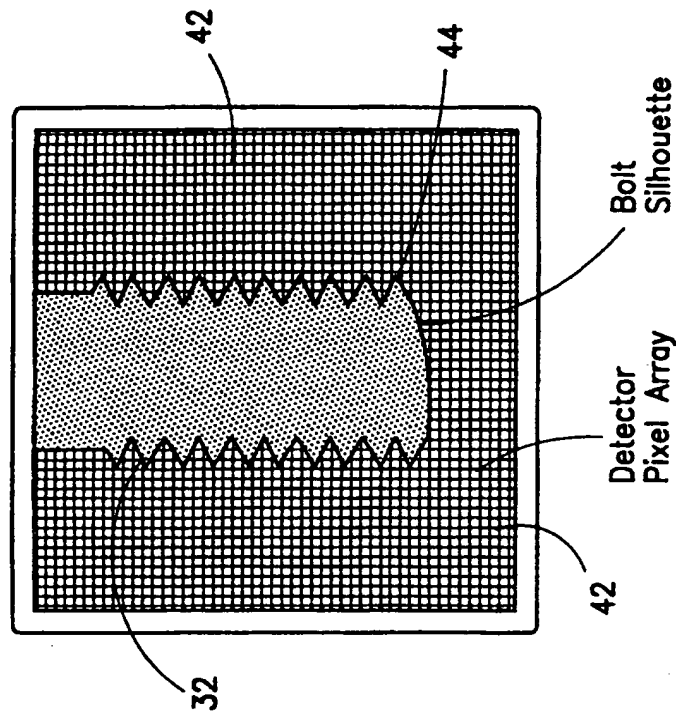


FIG. 4

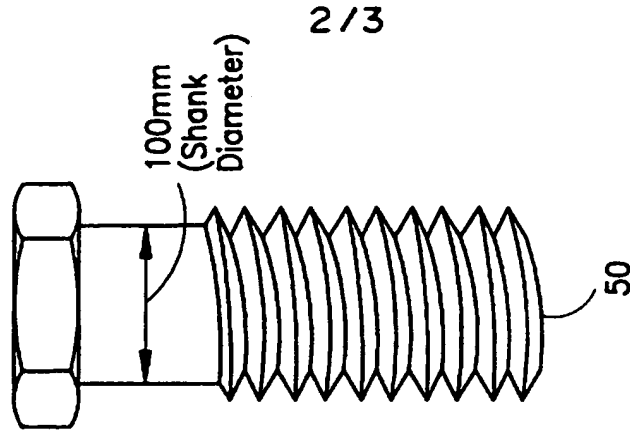


FIG. 5

3/3

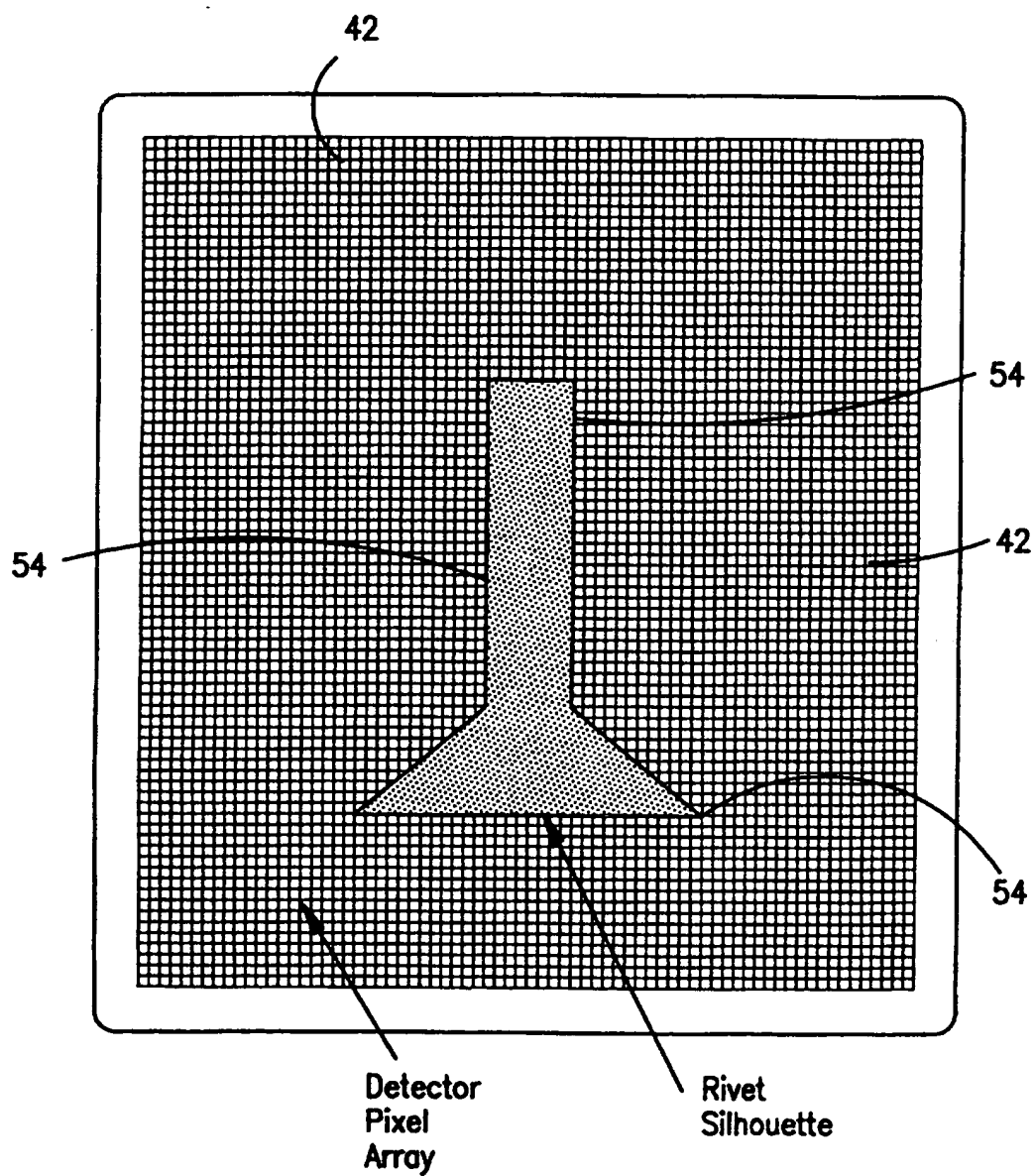


FIG. 6

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/14950

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(6) : GO1B 11/ 02 US CL : 356/372 According to International Patent Classification (IPC) or to both national classification and IPC				
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : Please See Extra Sheet. Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
Y	US, A, 3,515,487 (HATCHER ET AL) 2 June 1970, see detector array 11 in figure 1.	1-32		
Y	US, A, 3,549,896 (MASINO ET AL) 22 December 1970, see the collimated light beam and two-dimensional detector arrangement in figure 1.	1-32		
Y	US, A, 3,549,890 (KELLER AT AL) 22 December 1970, see figure 1.	1-32		
Y	US, A, 3,650,397 (BORNEMEYER) 21 March 1972, see figure 1.	1-32		
Y	US, A, 5,383,021 (HANNA) 17 January 1995, see figures 3 and 6.	1-32		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.				
<table border="0"> <tr> <td>           * Special categories of cited documents:            "A" document defining the general state of the art which is not considered to be of particular relevance            "E" earlier document published on or after the international filing date            "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)            "O" document referring to an oral disclosure, use, exhibition or other means            "P" document published prior to the international filing date but later than the priority date claimed         </td> <td>           "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention            "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone            "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art            "A" document member of the same patent family         </td> </tr> </table>			* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "A" document member of the same patent family
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "A" document member of the same patent family			
Date of the actual completion of the international search 16 MAY 1996		Date of mailing of the international search report 23 MAY 1996		
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer RICHARD A. ROSENBERGER Telephone No. (703) 308-0956		

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/14950

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,171,161 (JUNG) 16 October 1979, see figure 1	1-32
Y	US, A, 4,772,801 (FORNEROD ET AL) 20 September 1988, see figure 1.	1-32



# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US95/14950

## B. FIELDS SEARCHED

Minimum documentation searched

Classification System: U.S.

356/372, 378, 379, 383, 384, 385, 394, 240

250/559.12, 559.13, 559.15, 559.19, 559.21, 559.22, 559.24, 559.26